

ARIZONA DEPARTMENT OF TRANSPORTATION

REPORT NUMBER: FHWA-AZ91-840

LOW-VOLUME ROADS REHABILITATION STRATEGIES

State of the Art

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August 1991

Prepared for:

Arizona Department of Transportation
206 South 17th Avenue
Phoenix, Arizona 85007
in cooperation with
U.S. Department of Transportation
Federal Highway Administration

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Technical Report Documentation Page

1. Report No. FHWA-AZ-91-840		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle LOW-VOLUME ROADS REHABILITATION STRATEGIES				5. Report Date August 1991	
				6. Performing Organization Code	
7. Author (s) Michael S. Mamlouk				8. Performing Organization Report No.	
9. Performing Organization Name and Address Center for Advanced Research in Transportation Arizona State University Tempe, Arizona 85287-6306				10. Work Unit No.	
				11. Contract or Grant No. HPR-PL-1 (35) 840, RO 840 01P	
12. Sponsoring Agency Name and Address ARIZONA DEPARTMENT OF TRANSPORTATION 206 S. 17TH AVENUE PHOENIX, ARIZONA 85007				13. Type of Report & Period Covered State-of-the-Art Report	
				14. Sponsoring Agency Code	
15. Supplementary Notes Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration					
16. Abstract A literature search was conducted to evaluate various maintenance and rehabilitation techniques applicable to asphalt-paved low-volume roads (LVR) for possible use by the Arizona Department of Transportation (ADOT). The common method of LVR rehabilitation currently used by ADOT is the hot-mix asphalt concrete overlay. In this study, other rehabilitation techniques have been reviewed and suggested based on the experience of other highway agencies. These rehabilitation techniques include surface recycling, cold-mix in-place recycling, hot-mix recycling, fabrics, and thin overlays. The decision to use these rehabilitation techniques should not be based only on the initial construction cost but on a sound life cycle cost analysis. A good pavement management system should also be used in order to evaluate the cost-effectiveness of each technique so that more efficient decisions can be taken in the future.					
17. Key Words Low-Volume Roads, Rehabilitation, Asphalt Pavements, recycling, Fabrics			18. Distribution Statement Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161		
23. Registrant's Seal 					
19. Security Classification (of this report) Unclassified		20. Security Classification (of this page) Unclassified		21. No. of Pages 60	
22. Price					

ACKNOWLEDGEMENTS

The author would like to thank the Arizona Department of Transportation engineers who contributed to the preparation of this report including Larry Scofield, James Delton and Sylvester Kalevela. The financial support of the Arizona Transportation Research Center is also appreciated.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
--------	---------------	-------------	---------	--------

LENGTH

in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

in ²	square inches	645.2	millimetres squared	mm ²
ft ²	square feet	0.093	metres squared	m ²
yd ²	square yards	0.836	metres squared	m ²
ac	acres	0.405	hectares	ha
mi ²	square miles	2.59	kilometres squared	km ²

VOLUME

fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft ³	cubic feet	0.028	metres cubed	m ³
yd ³	cubic yards	0.765	metres cubed	m ³

NOTE: Volumes greater than 1000 L shall be shown in m³.

MASS

oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

TEMPERATURE (exact)

*F	Fahrenheit temperature	$5(F-32)/9$	Celcius temperature	*C
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APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
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LENGTH

mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

mm ²	millimetres squared	0.0016	square inches	in ²
m ²	metres squared	10.764	square feet	ft ²
ha	hectares	2.47	acres	ac
km ²	kilometres squared	0.386	square miles	mi ²

VOLUME

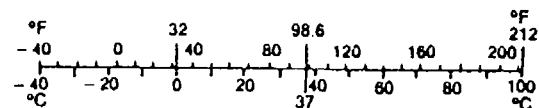
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m ³	metres cubed	35.315	cubic feet	ft ³
m ³	metres cubed	1.308	cubic yards	yd ³

MASS

g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T

TEMPERATURE (exact)

*C	Celcius temperature	$1.8C + 32$	Fahrenheit temperature	*F
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* SI is the symbol for the International System of Measurement

(Revised April 1989)

CHAPTER 1. INTRODUCTION

1.1 PROBLEM STATEMENT

There are many low-volume roads (LVR) in Arizona spread all over the state. Low-volume roads under the Arizona Department of Transportation (ADOT) jurisdiction include many miles of primary and secondary roads in rural areas, recreational roads in national forests, and access roads in Indian reservations. There is no exact definition for LVR, but it could be defined primarily as secondary or rural roads that have less than 400 vehicles per day as the design average annual daily traffic (AADT) (1). These roads may also have high percentages of heavy loads. At any given time the AADT on these roads can be drastically increased either temporarily or permanently in both volume and/or type and size of loads.

In many cases due to the existing terrain, agency practices, and/or available budgets these LVR have generally lower geometric standards and speed limits than roads with higher AADT. Other characteristics may include narrow bridges, unlit intersections, narrow traveled way widths, absence of shoulders, low water crossings, dips, blind curves, and steep grades. The pavement structures on many of these roads have evolved over time rather than having been designed and upgraded according to systematic procedures(1).

Generally the engineer/manager who is responsible for constructing and maintaining low-volume roads has: 1) few or no available trained roadway designers, 2) a small capital budget relative to the number of miles built, 3) a small annual maintenance and rehabilitation budget, and 4) in many cases, substandard road building materials available. Poor environmental conditions and unmonitored or uncontrolled heavy truck loads can also add to the difficulties in providing and maintaining such a low-volume network.

Most of the available literature on pavement design and rehabilitation is applicable to high-volume, high class facilities. Very limited literature is available which handles design and rehabilitation philosophies of LVR. Upgrading LVR could be different from upgrading high-volume roads. Thus, the asphalt concrete overlay commonly used for upgrading high-volume roads might not be necessary needed for LVR. ADOT is presently considering alternate pavement rehabilitation design strategies for use on LVR. These strategies would be applicable to primary and secondary roadways. The concept is to attempt to utilize proven inexpensive rehabilitation strategies on LVR so that a high percentage of funds could be utilized for the interstate highway system.

1.2 OBJECTIVE

The objective of this study is to review the available literature and identify potential rehabilitation strategies

appropriate for use on ADOT's LVR. A matrix of potential strategies is to be developed which indicates examples of expected life of strategy, cost, years of strategy has been applied, and sources of experience, etc.

1.3 SCOPE

Low-volume roads vary from unpaved roads to asphalt concrete or portland cement concrete paved roads. Since the vast majority of ADOT LVR are asphalt concrete and asphalt treated roads, the scope of this report is limited to these road types. Also, since not many new LVR are being built or expected to be built in the near future, this report concentrates on maintaining and rehabilitating existing LVR. Moreover, only rehabilitation techniques that could be of potential use to ADOT are considered. Finally, the report concentrates on rehabilitation strategies with a limited reference to maintenance techniques.

Chapter 2 of this report contains a summary of various maintenance and rehabilitation techniques that are published in technical reports and applicable to LVR. Examples of previous experience of ADOT and other highway agencies with selected rehabilitation techniques are reported in Chapter 3. Chapter 4 provides some rehabilitation methods for potential use by ADOT, while Chapter 5 includes conclusions of the study.

CHAPTER 2. MAINTENANCE AND REHABILITATION OF LOW VOLUME ROADS

2.1 BACKGROUND

Good quality hot-mix asphalt concrete overlay is desirable but costly when compared to other low-cost rehabilitation strategies. Lower-cost alternatives are found, in some cases, to perform as well as the more costly processes for LVR. Quite a bit of information is available from many sources for the relatively higher-cost rehabilitation techniques, but little information seems to exist for the less-costly alternatives. The problem is to find out which alternative will be successful for a particular situation, under what conditions, how long it will last without excessive maintenance, what specifications should be used, what are the costs, and what materials will work. Many highway engineers, including ADOT engineers, have tremendous amount of experience and knowledge in LVR technology; however, much of it is not formally documented.

Rehabilitation for a low-volume road is significantly affected by the expected roadway use and function. A number of important questions that must be answered are (1):

- * Is the road expected to be all-weather?
- * Will the road carry heavy commercial truck traffic?
- * What is the essentiality of the route?
- * What is the expected design life and how much

maintenance can be expected?

- * What is the required ride quality?
- * What is the detour alternative, if any?

Some LVR are primarily used only in certain seasons such as roads at higher mountain elevations. However, many conditions require roads to be all-weather including access to medical aid, life support services, schools, emergency services, or other forms of transportation.

Considerations for low-volume road performance include structural performance, functional performance, and safety. The structural performance of a LVR surface relates to its physical condition, i.e., occurrence of cracking, rutting, faulting, ravelling, or other conditions that adversely affect its load-carrying capability or require maintenance. The functional performance of a low-volume road concerns how well it serves the user. In this context, riding comfort or ride quality is the primary concern for paved surfaces. Safety, on the other hand, is related to skid resistance and other factors which are not discussed in this report.

In addition to considering such LVR factors as structural load capacity, roughness, pavement distress, skid resistance, road function, traffic, and subgrade quality, the economics of each design or rehabilitation option must be reviewed. Most LVR decisions are based only on initial costs, although there is a need to consider the total life cycle costs of design, maintenance, and rehabilitation alternatives. Life cycle cost analysis is the most accurate

way to compare several feasible design or rehabilitation options, particularly if stage construction is one of the alternatives. Life cycle costs (LCC) also help in the preparation of budget requests. However, LCC analysis is not used in many cases for the following reasons: 1) a lack of input data, 2) unknown interest rates, value of money, or inflation, 3) the appropriate method to use, and 4) too involved for LVR (1).

The data needed to develop life cycle cost estimates are:

- * Estimates of alternative surface design, rehabilitation, and maintenance actions and their life expectancies.
- * Total costs of each action for all alternatives.

The costs required to make LCC comparisons are:

- * Initial construction costs.
- * Future maintenance costs.
- * Future rehabilitation or reconstruction costs.
- * Peripheral costs such as raising drainage inlets for overlays.
- * User costs.
- * Salvage values.

The recommended method of LCC analysis for comparing different alternatives is either the present worth cost method or the equivalent uniform annual cost method. These methods make good use of available information and provide a suitable framework if differential rates of inflation are

considered. Details of LCC analysis are discussed elsewhere (2).

The purposes of maintenance and rehabilitation are 1) to keep a roadway in a desirable condition to adequately serve the public or 2) to restore a road to its original condition or upgrade its original surfacing type. Many forms of maintenance and rehabilitation are available. Maintenance refers to periodic work activities that are intended to keep a roadway in a suitable condition. Maintenance may also refer to reactive work which is performed when a noticeable deterioration of the roadway has occurred and can easily be corrected. Rehabilitation refers to a more extensive action that is taken to correct a roadway which has deteriorated to some minimum acceptable level. Rehabilitation is normally done to return a road to its original condition once it has seriously deteriorated or to improve the road to a "better than original" condition in order to upgrade the level of service provided to the traveling public. Basic alternatives and procedures are recommended in this chapter for low-volume road maintenance and rehabilitation.

A feasible maintenance or rehabilitation alternative addresses the cause of the distress and is effective in repairing the existing deterioration and thus prevents its recurrence. Some projects have only one or two feasible alternatives. Table 2.1 contains alternative maintenance and rehabilitation methods for specific distress types. For

Table 2.1. Candidate maintenance and rehabilitation methods of asphalt pavement distress

Distress	Maintenance/ Rehabilitation Methods
Alligator Cracking	Full-Depth Spot Repairs Overlay Recycle
Bleeding	Apply Hot Sand Chip Seal with less binder
Block Cracking	Slurry Seal Chip Seal Overlay Recycle Seal Cracks
Depression	Level-Up Overlay
Polished Aggregate	Chip Seal Slurry Seal Open-Graded Overlay
Potholes	Full-Depth Repairs Patch Recycle
Pumping	Full-Depth Repair Add Subdrainage Crack Seal Subseal
Raveling and Weathering	Chip Seal Slurry Seal Fog Seal Sand Seal Stress Absorbent Membrane
Rutting	Overlay Cold Mill Hot Recycle
Swell	Removal and Replace

each distress type, one or more rehabilitation or maintenance method may be applied depending on the cause and severity of the distress as well as other factors (1).

2.2 MAINTENANCE TECHNIQUES

Maintenance should be performed on low-volume roads both on a routine basis and as necessary to maintain the road in a good condition to serve the public. The two types of maintenance are routine maintenance which is performed on a scheduled basis, and special maintenance which is performed on an unscheduled basis in response to special situations. Routine maintenance is performed to prevent or minimize the occurrence of more serious distresses and to extend the service life of the facility. Special maintenance is performed to correct situations that could otherwise lead to extensive damage requiring major rehabilitation as discussed below. More details of maintenance techniques are published elsewhere (3-6).

2.2.1 Crack Sealing - Surface cracks should be sealed to prevent water from entering and destroying the base course. Crack sealing is a routine maintenance activity that should be performed on a scheduled basis as defined by local experience as to its cost-effectiveness. It is most effective or warranted in wet environments. The types of cracks which are candidates for sealing include longitudinal, transverse, random, block, and reflection cracks. Load-associated cracks that are not candidates

include alligator cracks, slippage cracks, and edge cracks. These load-associated cracks are more effectively repaired by removing the bad areas and placing a full-depth patch or a structural overlay. Candidate cracks should be sealed when they are wide enough to accept a sealant (approximately 1/4 inch wide) (7). Severe cracks (wider than 3/4 inch) are candidates for more comprehensive rehabilitation work such as crack sealing followed by a chip seal or overlay. These wide cracks can also be individually sealed with a slurry, sand emulsion, or bituminous mix if rehabilitation is not economically feasible.

Materials that act as good sealants are asphalt rubber, silicone, cold-pour sealant, and polymerized asphalts. Cold-pour and polymerized asphalt sealants are relatively new and appear to provide good field performance.

2.2.2 Patching - Asphalt concrete pavement surfaces occasionally develop potholes which require patching. This type of maintenance activity can be either routine or special. If severe potholes occur unexpectedly on a section of roadway, maintenance forces should be dispatched as soon as possible to prevent further pavement damage and thus restore user safety. Otherwise, pothole patching can be scheduled on a routine basis throughout the year. The heaviest work load normally follows the spring thaw and heavy rainfall seasons. Either partial-depth or full-depth patching could be performed depending on the severity of the pavement distress (3).

2.2.3 Maintenance at Utility Cuts - Maintenance of utility cuts is a special activity which is only required when a utility cut has been made and the initial patch is not performing well. Normally, the utility company that made the cut is responsible for patching the cut and returning the pavement to serviceable condition. When possible, a lean concrete mix should be used as backfill to reduce subsidence. The type of maintenance required on utility cuts depends on the severity of the problem.

2.2.4 Surface Seal Coats - The term seal cost is generic and refers to a wide variety of bituminous applications for both paved and aggregate-surfaced LVR.

They may be classified as

- * Surface Treatments
 - Chip Seals (single and multiple)
 - Sand Seals
 - Fog Seals
 - Asphalt Rubber Seals
- * Slurry Seals

Chip seals have wide application for low-volume roads. Sand seals, slurry seals, and fog seals are used mostly as maintenance items, but may also be used as low-cost surfacing over existing pavements. Most bituminous seal coat applications use asphalt emulsions (water-based) as a binder, although cutback asphalts (oil-based) are still used in some rural areas (EPA restricts cutbacks in some areas).

Many jurisdictions have been using emulsions exclusively for more than 25 years for bituminous seal coats.

Surface treatments provide an extension to pavement service life and reduce maintenance expenditures. The major functions of surface treatments are

- * Provide a new wearing surface
- * Seal cracks
- * Waterproofing
- * Improve friction
- * Reduce weathering effects
- * Improve surface appearance
- * Visual delineation
- * Some structural benefits are provided by multiple surface treatments

Surface treatment application is an art that requires close attention to details and quality. There are many things that could go wrong during the surface treatment applications and should be avoided (5).

A single surface treatment approach is especially suited for light traffic and as an interim or preventive rehabilitation procedure. It also may be used following crack sealing operations.

A double surface treatment can produce a pavement thickness on the order of 1/2 to 3/4 inches that will provide some extra reinforcement to the pavement. In a double surface treatment, the largest size stones in the first course determine the surface layer thickness. The

second course serves to fill the voids in the mat of the first course aggregate.

A multiple surface treatment is usually applied on a prepared consolidated gravel, crushed stone, water bound macadam, earth, stabilized soil, or similar base. Multiple surface treatments are also conducive to stage construction and, if properly constructed, will reduce the level of road maintenance relative to granular-surfaced roads.

Sand seals are defined as a spray application of asphalt emulsion followed with a light covering of fine aggregate such as clean sand or screenings.

A fog seal involves spraying a bituminous material on an existing pavement without the addition of aggregate for the purpose of rejuvenating the pavement surface and prolonging the need for more expensive preventive maintenance.

An asphalt rubber seal is a special type of asphalt-aggregate surface treatment. The asphalt material is replaced with a specialized blend of 20 percent or more of crumb rubber and asphalt cement. In addition to the asphalt rubber seal, asphalt rubber concrete can be used as discussed in Section 2.3.3.

A slurry seal is a mixture of well-graded fine aggregate, mineral filler, emulsified asphalt, and water. It is used in both the preventive and corrective maintenance of asphalt pavement surfaces. It is usually applied in

thicknesses of 1/8 to 1/4 inch and therefore does not increase the structural strength of the pavement.

The cost of slurry seals may be less expensive than most commonly used asphalt overlays. They may or may not be more cost-effective in a life cycle cost analysis. Slurry seals are considered to have a nominal life of 3 to 7 years compared to an asphalt overlay that may be designed for 7 to 15 years or more.

Materials to be used in sealing pavements include an appropriate type of asphalt and aggregate chips or sand. Asphalt types which are acceptable for both chip and sand seals include, RS-1, RS-2, CRS-1, CRS-2, CRS-2h, CSS-1, AC-2.5, AC-5, MS-1, and HFMS-1. Aggregates or sand that will be used for texture must be free from dust which may require washing. Chips should have a maximum size of about 1/4 to 1/2 inch and should be relatively uniform in size.

Besides the maintenance required on the pavement surface, there are several other surface-related items that need periodic or routine maintenance. These include maintenance of drainage facilities, roadside areas, and traffic control markings and devices.

ADOT has been using various maintenance techniques mentioned above on LVR with the exception of asphalt rubber seal. The experience of the state with asphalt rubber is in the form of asphalt rubber concrete as discussed in Section 2.3.3.

2.3 REHABILITATION TECHNIQUES

Many different rehabilitation techniques can be applied to pavements to extend their lives, restore them to a near new condition, and/or upgrade their structural load capacity. When evaluating alternative rehabilitation methods, several factors must be considered, including the surface distress, structural condition, and functional condition of the existing pavement. This section describes LVR rehabilitation techniques and their application. The maintenance treatments described before may need to be applied in combination with a particular rehabilitation treatment (for example, full-depth patching of weak or failed spot prior to overlay). The following sections describe main categories of rehabilitation treatments (1).

2.3.1 Hot-Mix Asphalt Concrete Overlay - Overlays improve the serviceability of a pavement structure and its structural load-carrying capacity or upgrade the initial construction. The design of overlay alternatives requires a detailed investigation of the existing pavement to provide the data required to determine the final strategy. This review should include a survey of pavement distress, roadway drainage characteristics, and also the type, thickness, and condition of each existing pavement layer. Figure 2.1 shows a general framework for overlay designs based on nondestructive deflection measurements (8).

The 1986 AASHTO Pavement Design Guide incorporates mechanistic procedures for overlay design (9). These

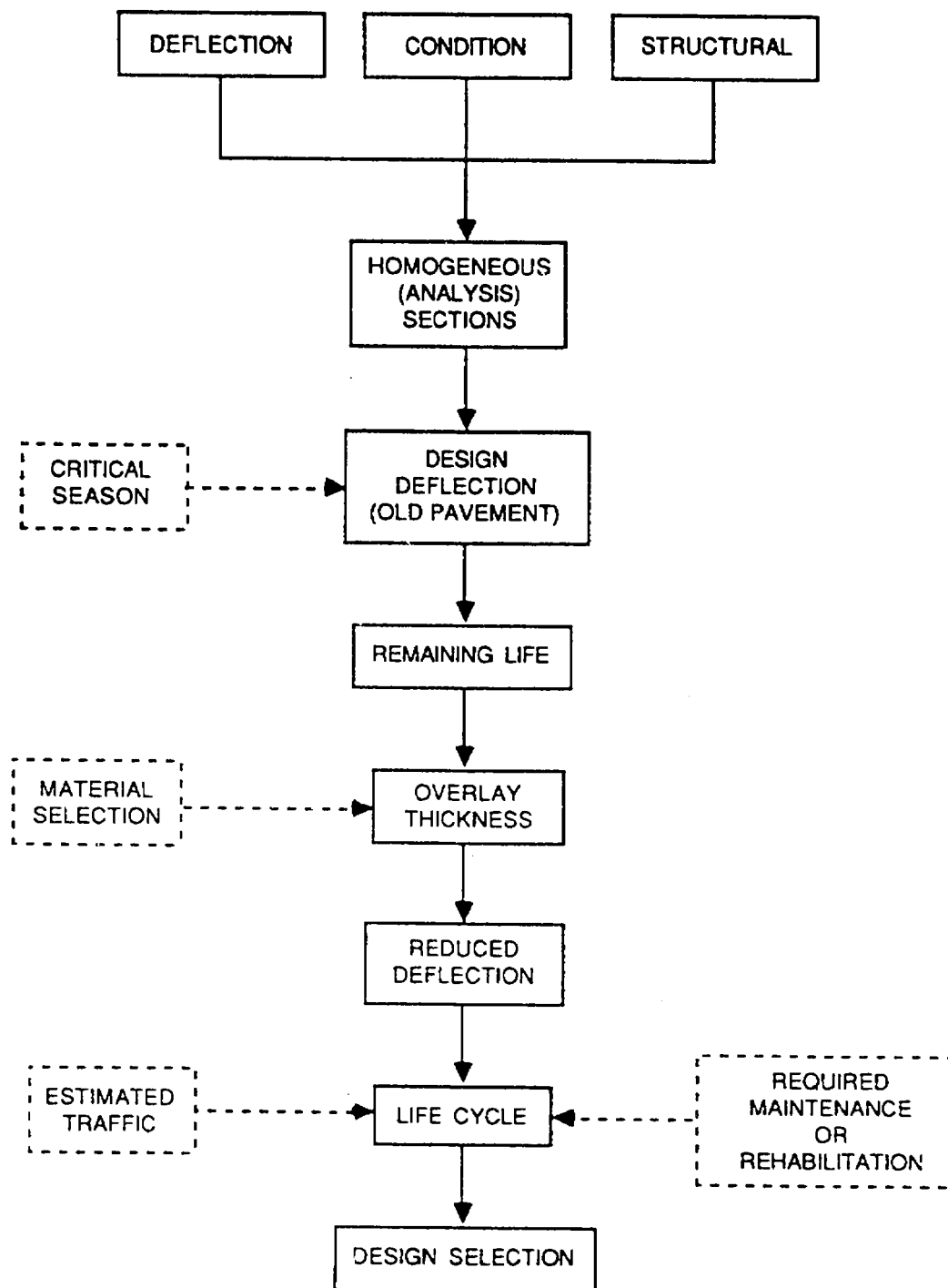


Figure 2.1. Framework based on deflection measurements for overlay design

procedures are generally too complicated to be recommended for LVR use (1). Other methods of overlay design that may be more suitable to LVR are published by the Asphalt Institute (10,11). The first method (10) is applicable to light and medium traffic pavements, while the second method (11) is applicable to pavements which carry more than a hundred heavy trucks per day.

2.3.2 Recycling - Pavement recycling is the reuse of material which has been removed from in-place pavements and processed to produce quality paving materials suitable for use in new construction or in the rehabilitation of pavements (1, 12, 13).

The need to recycle existing asphalt pavement materials for the reconstruction and rehabilitation of asphalt pavements is increasing. Recycling can help both to optimize the use of available materials and energy supplies, and to decrease the cost of maintaining highways, roads, and streets.

As techniques for recycling improve, and specification writing agencies and contractors become familiar with the various processes available, the use of recycling has begun to demonstrate cost savings over the use of new materials for major maintenance and rehabilitation of pavements. The Federal Highway Administration estimates the pavement industry generated \$105.5 million in savings using recycled materials in 1985. Most of the states have accepted some form of asphalt recycling in their specifications.

Recycling should be considered on a local basis for any project.

Asphalt pavement recycling is performed by one of the three procedures: surface recycling, cold-mix recycling, or hot-mix recycling as shown in Figure 2.2.

2.3.2.1 Surface Recycling - Asphalt pavement surface recycling is limited to less than about 2 inches, with 1 to 2 inches being typical. Surface recycling is only suitable for correcting surface distress, such as minor raveling, nonload-associated cracking, minor corrugations, minor rutting, low surface friction due to polished aggregate, minor flushing or bleeding, poor construction practices, and poor drainage profile not due to pavement structure or subgrade deficiencies.

A wide variety of pavement surface removal equipment has been developed and a number of innovative techniques established. This equipment and the associated techniques can be categorized into 1)cold-planers, 2)heater-planers, 3)cold-millers, and 4)heater-scarifiers. The first three types of equipment are generally used for pavement removal only and therefore are not technically part of a surface recycling process, though the removed material can be recycled in a separate operation.

Cold-planers are normally motor grades with hardened steel blades. The primary purposes of cold-planing are to remove corrugations, to reduce the amount of rutting, and to

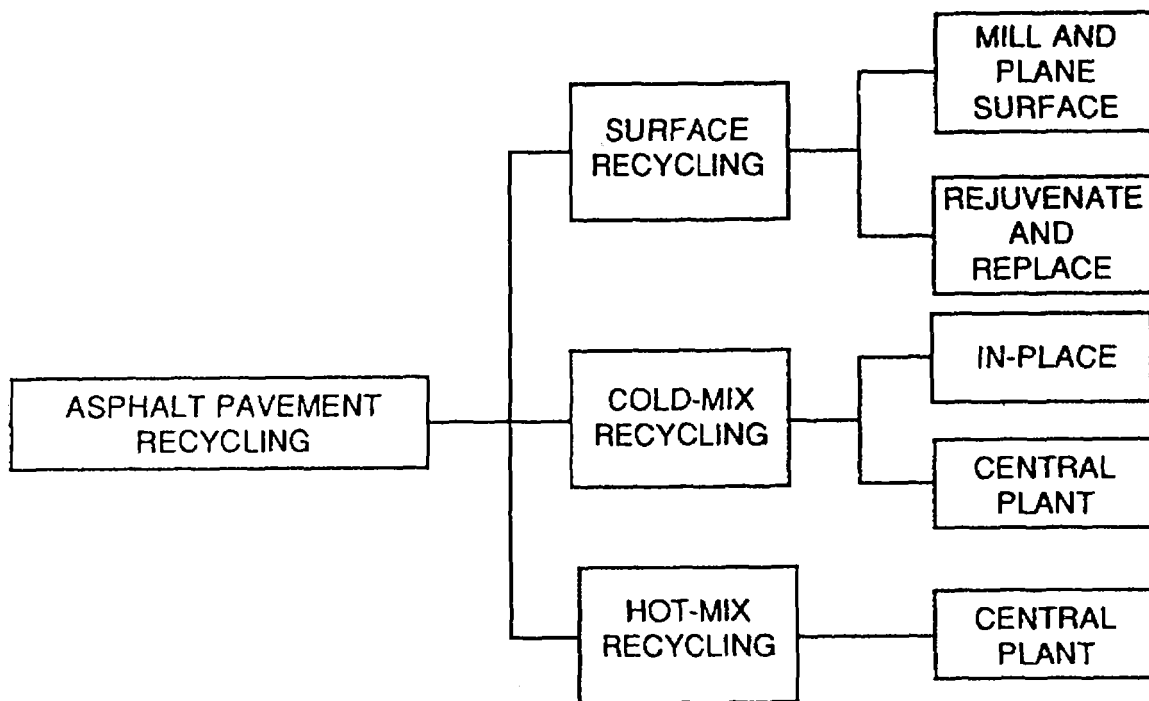


Figure 2.2. Categorization of asphalt pavement recycling

remove improperly designed and constructed chip seals or slurry seals.

Heater-planers involve the use of heating units that precede the planer, or single pieces of equipment that can both heat and plane the pavement.

Cold-milling has become quite popular in many areas in recent years. The major purpose of cold-milling is removal of surface deterioration by means of a rotating drum lined with tungsten-carbide-tipped cutting teeth that grind the pavement. Millings can be used for unstabilized base courses or recycled into stabilized base and surface courses. The millings can be recycled either in-place or at a central plant.

After removal of the surface material through cold milling, most pavements are overlaid. Some projects have been milled and opened to traffic without placement of an overlay; however, high tire noise generated public complaints. If the pavement is structurally sound but rough from various nonload-associated distresses, this may be a cost-effective means of delaying placement. The milled surface is not too rough and should provide acceptable service for a few years (1).

The most common surface recycling process is heater-scarifying, which involves the heating and scarification of an asphalt pavement surface. The operation may include the addition of new asphalt or other modifier. Scarification is usually limited to a depth of 1 inch in a single pass,

though some equipment is capable of deeper penetration. The basic recycling operation using the heater-scarifying approach consists of preparing, heating, and scarifying the surface, adding additional materials, if required, compacting and making final adjustments to manholes and drainage structures. Figure 2.3 shows possible variations in the heater-scarifying process.

In order to be suitable for the heater-scarifier process, the pavement section should contain at least 3 inches of an asphalt mixture and the surface course should not contain aggregate larger than 1 inch. Heater scarifiers are large pieces of equipment and may not be practical for steep and curving mountain roads (1).

The depth of scarification is the most critical element. The deeper the scarification, the better the finished product will be. In some circumstances, surface recycling with an overlay has advantages over the placement of a conventional overlay. Since overlays eventually mirror the surface on which they were laid, in the long run, surface recycling produces a smoother final overlay surface and can reduce reflective cracking. Also, when properly executed, the process creates a strong bond between the old and new asphalt layers, and the omission of a tack coat (which is frequently required by owners on regular overlays) is another expense that can be avoided. Asphalt or modifier is sprayed on the scarified surface before the overlay is placed. Since the recycling process uses in-place material

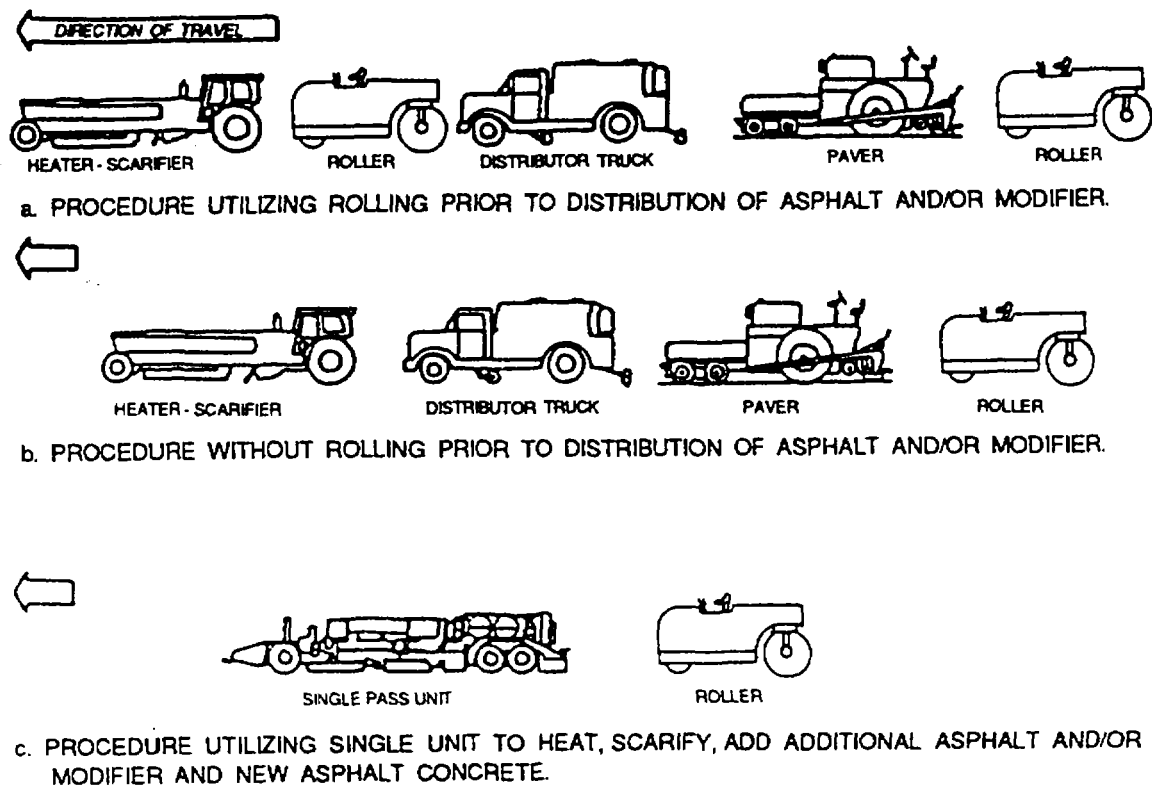


Figure 2.3. Variations in the heater-scarifying process

in the leveling procedure, there can be a reduction in the thickness of overlay required and, in some cases, no overlay is required.

2.3.2.2 Cold-Mix Recycling - Cold-mix asphalt recycling is a process in which reclaimed asphalt pavement (RAP) materials, new aggregate and/or reclaimed aggregate materials (RAM), or both, are mixed with new asphalt and/or recycling agents to produce cold-mix base mixtures. The mixing may be done in place or at a central plant, and the process does not require the addition of heat. The cold recycled base is usually covered with a hot-mix wearing surface or asphalt surface treatment to provide a water and abrasion resistant surface.

Figure 2.4 is a summary flow chart of available procedures for cold in-place surface and base recycling (12). Figure 2.5 shows typical in-place recycling operation with modifier agent and additional binder (12). Cold-mix asphalt recycling can have many advantages, including (14)

- * Significant pavement structural improvements can be achieved without changes in horizontal and vertical geometry.
- * All types and degrees of pavement distress can be treated.
- * Reflection cracking can be eliminated if the depth of pulverization and reprocessing is adequate.
- * The pavement ride quality can be improved.

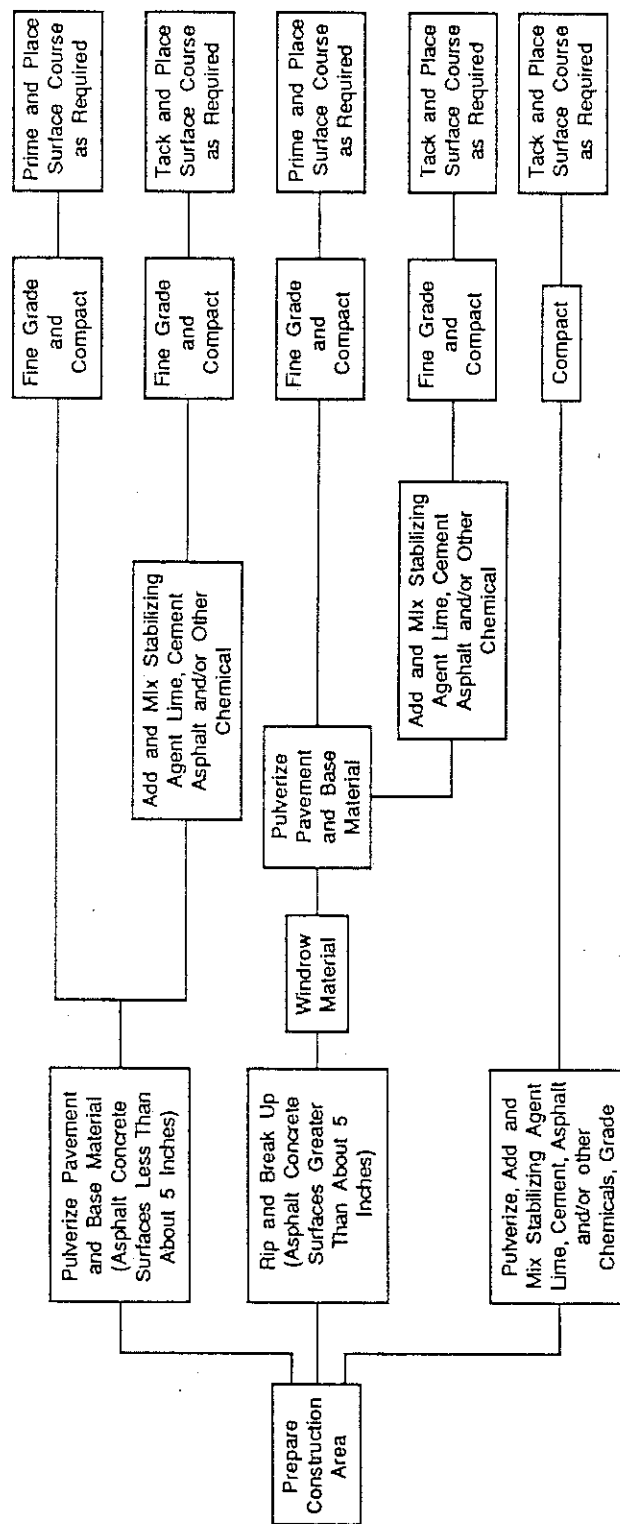


Figure 2.4. Procedures for cold in-place surface and base recycling

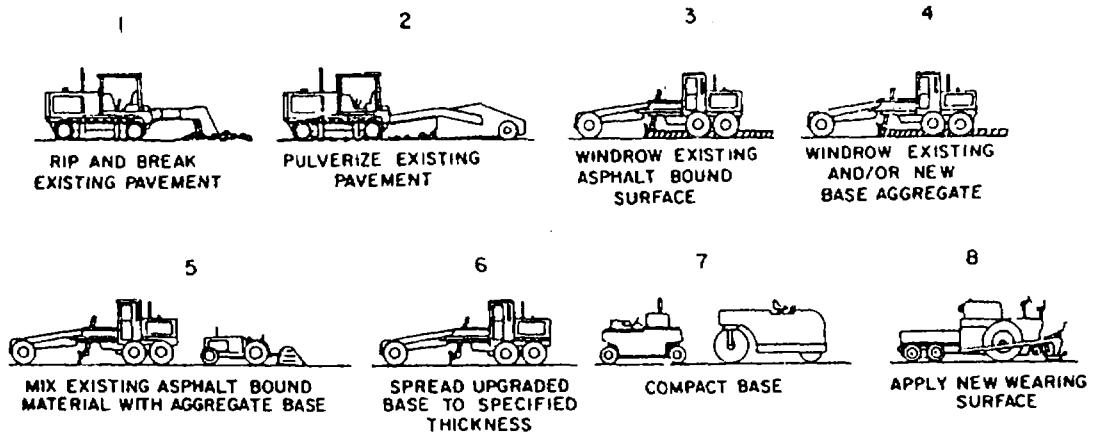


Figure 8. Typical in-place recycling operation without restabilization.

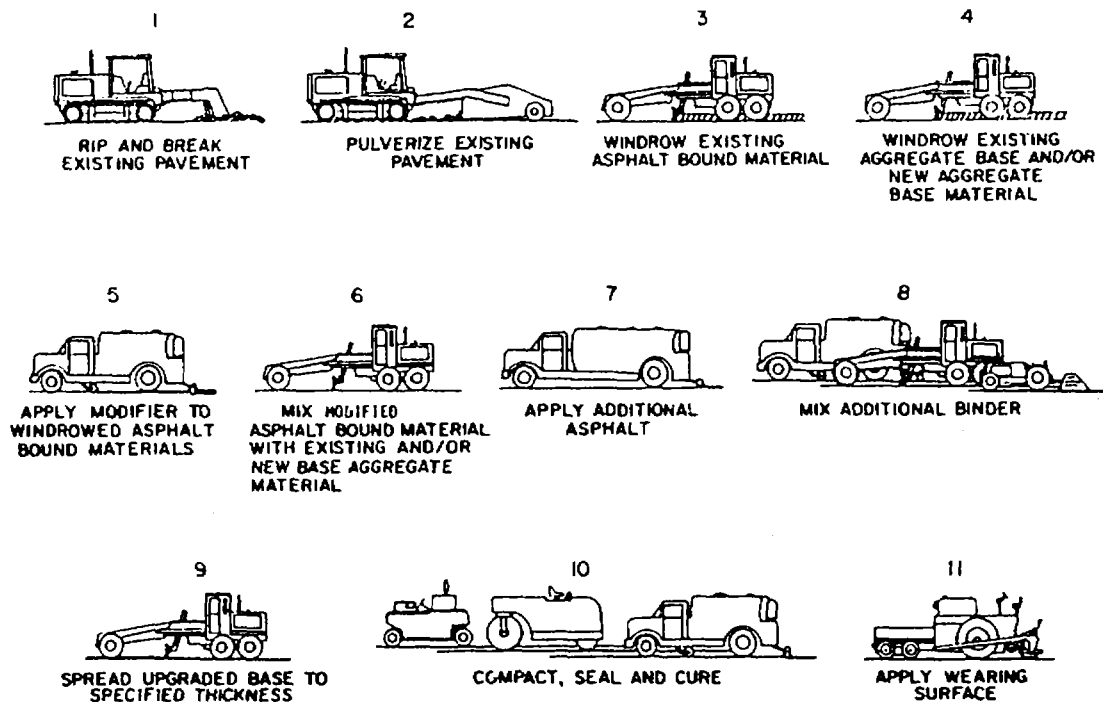


Figure 2.5 Typical in-place recycling operation with
modifier agent and additional binder

- * Skid resistance can be improved (depending upon type of surface placed on cold recycled section).
- * Hauling costs can be minimized if processing takes place on grade.

The disadvantages include:

- * Quality control for in-place operations is not as good as for central-plant operations.
- * Traffic disruption can be greater than with some other types of rehabilitation activities.
- * Curing is normally required for strength gain.
- * Depending on type and age, pulverization equipment can be in need of frequent repair and thus production rates can be low.

There are five steps in the construction of a cold recycled asphalt pavement.

- 1) Pavement removal and size reduction.
- 2) Addition of new asphalt/recycling agent and mixing.
- 3) Laydown and aeration.
- 4) Compaction and curing.
- 5) Application of wearing surface.

The initial step for any type of cold recycling process is to rip, scarify, pulverize, or mill the existing pavement to a specified depth. The broken-up material can then be further reduced in size (if necessary) and mixed with new asphalt and/or recycling agent in-place, or it can be hauled to a central plant location where it is crushed (if

necessary), stockpiled, fed into a conventional batch or drum plant for mixing, and hauled back to the job site for laydown and compaction. The choice of method depends on equipment availability, condition of the existing roadway, and economics. For example, in-place recycling is especially applicable to secondary low-volume roads that are located a considerable distance from a central plant. On the other hand, central-plant mixing allows better quality control and affords the best opportunity to produce a uniform recycled mix, since the reclaimed material can be segregated into various stockpiles, based on property variation, and then reblended (15).

The "pulverization-and-mixing-train" concept was introduced in 1978 where a cold planing machine was used to feed pulverized material directly to a Midland mix paver in Livingston County, Michigan (15). The mix paver, which consists of an asphalt storage tank, asphalt spray bar system, twin-shaft pugmill, and normal paver screens, was used to mix an asphalt cement with the reclaimed material. The recycled mixture was placed back on the same county roadway by the mix paver and compacted by normal rolling equipment and procedures. The idea of pulverization and mixing train was improved and used in many cold, in-placed recycling jobs through the country.

The first Arizona pulverization-and-mixing-train was used in Globe, Arizona (16).

2.3.2.3 Hot-Mix Recycling - Hot-mix recycling is a process in which reclaimed asphalt pavement materials, reclaimed aggregate materials or both, are combined with new aggregate and/or asphalt, and/or recycling agent, as necessary, in a central plant blending and mixing operation to produce hot-mix paving mixtures. The finished product is generally required to meet standard materials specifications and construction requirements for the type of asphalt concrete mixture being produced. With equipment now available, hot-mix producers can recycle using relatively inexpensive additions or modifications to their existing plants, or using plants designed specifically for recycling without violating air quality regulations. Hot-mix recycling can be a standard procedure in road maintenance and rehabilitation practices if it satisfies the following economical, technical, and environmental needs of the highway engineer (17).

- * Achieve productivity levels similar to conventional hot-mixes.
- * Produce stable mixes equivalent to new asphalt mixes. Both the aggregate and asphalt in the recycled mix must meet the same requirements as new materials.
- * Be an environmentally acceptable system (i.e., limits "blue smoke" during production).

2.3.2.4 Advantages and Disadvantages of Recycling - Recycling of existing pavements for construction,

rehabilitation, and maintenance purposes offers the following potential benefits (1):

- * Reduced cost.
- * Preservation of existing pavement geometrics.
- * Conservation of aggregates and binders.
- * Energy conservation.
- * Preservation of the environment.

While recycling as a rehabilitation alternative has many advantages, there are problems that local road agencies must consider. There may not be local contractors with the experience or equipment to do the work, especially cold in-place recycling or surface recycling. Local road agencies should consider making recycling a bid alternative to help create a market in that area. A shortage of qualified contractors can inhibit competitive bidding and reduce the cost-effectiveness and material suppliers may resist recycling, and discourage qualified recycling contractors from marketing in that area. Long haul distances from central plant operations of non-local contractors could make recycling more expensive than using local virgin materials (1).

The amount of local work for which recycling is applicable may be insufficient to justify the purchase of new equipment (or modification of existing equipment) by contractors or the local road agency. Another problem is that the most common pavement type in a particular region may not be conducive to the use of recycling for

rehabilitation. Also, deficiencies in the quality of the reclaimed material (gradation, resistance to abrasion, etc.) can make recycling economically unattractive.

Due to the increasing salvage or recovered value of existing pavement materials, the high cost of energy, the improvements in recycling equipment and technology, and the increase of agency and contractor confidence in recycling, it is anticipated that pavement recycling will become more cost-effective. Numerous projects throughout the United States have shown that bid prices can be consistently lower with all types of recycling.

Table 2.2 (12) lists advantages and disadvantages associated with different recycling methods.

2.3.3 Asphalt Rubber - Asphalt-rubber refers to a blend of asphalt with 18-23% granulated rubber (18). The asphalt and rubber are blended at high temperatures and with sufficient shearing action to promote chemical and physical bonding of the rubber with the asphalt. A diluent oil is used to reduce the viscosity of the asphalt rubber for construction. Hot asphalt-rubber is sprayed onto the pavement surface with a modified distributor truck and covered with either 1/4 or 3/8-inch chips to form a stress absorbing membrane (SAM). A stress absorbing membrane interlayer (SAMI) is constructed by covering a SAM with an asphalt concrete overlay.

Table 2.2. Major advantages and disadvantages of asphalt pavement recycling techniques

RECYCLING TECHNIQUES	ADVANTAGES	DISADVANTAGES
SURFACE	<ul style="list-style-type: none"> • Reduces frequency of reflection cracking • Promotes bond between old pavement and thin overlay • Provides a transition between new overlay and existing gutter, bridge, pavement, etc. that is resistant to raveling (eliminates feathering) • Reduces localized roughness due to compaction • Treats a variety of types of pavement distress (raveling, flushing, corrugations, rutting, oxidized pavement, faulting) at a reasonable initial cost • Improved skid resistance 	<ul style="list-style-type: none"> • Limited structural improvement • Heater-scarification and heater-planing has limited effectiveness on rough pavement without multiple passes of equipment • Limited repair of severely flushed or unstable pavements • Some air quality problems • Vegetation such as turf shoulders or ditch linings may be damaged • Mixtures with maximum size aggregates greater than 1-inch cannot be treated with some equipment • Limited disruption to traffic
IN-PLACE	<ul style="list-style-type: none"> • Significant structural improvements • Treats all types and degrees of pavement distress • Reflection cracking can be eliminated • Frost susceptibility may be improved • Improve ride quality • Improve skid resistance • Minimizes hauling 	<ul style="list-style-type: none"> • Quality control not as good as central plant. • Traffic disruption • PCC pavements cannot be recycled in-place • Curing is often required for strength gain
CENTRAL	<ul style="list-style-type: none"> • Significant structural improvements • Treats all types and degrees of pavement distress • Reflection cracking can be eliminated • Improve skid resistance • Frost susceptibility may be improved • Geometrics can be more easily altered • Improved quality control if additional binder and/or aggregates must be used • Improve ride quality 	<ul style="list-style-type: none"> • Potential air quality problems at plant site • Traffic disruption

Rubber results in significant improvement in the elasticity of asphalt. However, the asphalt rubber is a highly variable material whose properties could not be fully evaluated and controlled with conventional tests used for asphalt cements (18).

Field research projects constructed by ADOT and other highway agencies demonstrated good performance of both SAM and SAMI sections. More technical information and performance of asphalt rubber projects can be obtained from the Asphalt Rubber Producers Group in Phoenix, Arizona.

2.3.4 Foamed Asphalt - Foamed asphalt was developed in the 1950's by Csanyi of Iowa State University. The purpose for foaming the asphalt was to lower the viscosity and increase the volume of the asphalt so that there would be better dispersion of the asphalt on cold, wet aggregate. Foamed asphalt does not require solvents or emulsions, so the environmental and financial drawbacks associated with cutback and emulsified asphalts are eliminated (19).

The foamed asphalt process involves foaming by injecting cold water into the hot asphalt cement and spraying the foam onto the aggregate while mixing in a mixing chamber. The asphalt appears to coat the fines, and can be applied to moist, cold aggregate.

Several advantages are offered by the use of foamed asphalt as compared to other asphalt applications. A slightly lesser amount of asphalt is generally needed for

foaming than in other kinds of asphalt applications. The foamed asphalt is sprayed onto the cold, wet aggregates and coats the aggregates better than if the asphalt were not foamed. To get the same amount of coverage as the foamed asphalt with "unfoamed" asphalt, either the aggregates would need to be hot and dry, or else more asphalt would be necessary.

The hydrocarbon pollutant release when paving with foamed asphalt mix is less than that when paving with cutback or emulsified asphalt mixes (notably during the aeration period for the cutback or emulsified asphalt -- in fact, there is generally no need for an aeration period with foamed asphalt). The asphalt is foamed by virtue of an injection of 1 to 2 percent cold water into hot (approximately 350°F) asphalt. The foamed mix is stable upon compaction and does not need to cure or "break."

The foamed asphalt process is not expensive once a foamed asphalt generator has been made available. The aggregate is used in a cold, wet condition and thus requires no heating or drying. As indicated before, there is no aeration period, so weather plays a small role during field compaction. Foamed asphalt-aggregate mix has even been stockpiled for up to a year before placement and compaction, so there is less waste as compared to other asphalt mixes (20).

Durability of foamed asphalt mixtures has been questioned. The concern is due to foamed asphalt mixtures

having lower bitumen contents and higher voids content than are generally found in standard asphalt mixes (21). A common problem limiting the durability of asphaltic concrete is that of the asphalt being stripped from the aggregate by water. Certain chemicals have been found to increase the bonding power of asphalt to aggregates (22). Lime has been used successfully as an additive to asphaltic concrete in the past. Silane, the name of a family of organic chemicals, has recently been used as an additive to asphaltic concrete specimens. Silane has been recommended as a possible anti-stripping agent (23). It can either be added directly to the asphalt or used as an aggregate pretreatment. Indulin, typical of several liquids which are marketed as anti-stripping agents, has been added directly to the asphalt before the asphalt is foamed.

Comparatively little research has been done on foamed asphalt because of its suspected lack of durability after saturation and freeze-thaw cycles. Previous attempts to address the durability question have been discouraging. Foamed asphalt specimens subjected to various types of saturation and freezing and thawing have often fallen apart or been too damaged to test afterwards (19).

2.3.5 Fabrics - Porous woven and non-woven fabrics have been used in road construction for many years. Non-woven fabrics have been tried extensively for enhancement of existing pavements. Considerable success has been claimed (24). Although the theory behind the benefits achieved is

not well established, it appears to be the result of: a) waterproofing, and b) the formation of a stress-relieving layer. The most common use has been to prevent reflection cracking.

Some researchers report that the fabric layer can be substituted for 1 to 1-1/2 inches of asphalt concrete in a pavement. If this conclusion is true, it is probably more a result of waterproofing than a strength contribution of the membrane. The membrane can effectively eliminate surface water in the pavement due to surface infiltration, thereby stabilizing the internal pavement environment and the subgrade. The high elongation properties of the fabrics and fabric filaments normally preclude their making a large contribution to the pavement strength at the comparatively low strain normally encountered in adequately performing pavements.

Majidzadeh (25) states that the structural requirements must be satisfied before the beneficial effects of the fabric can be demonstrated. A close examination of other research data resulting primarily from test road sections appears to substantiate this conclusion.

The construction method consists of (24):

- 1) Cleaning and filling all cracks over 1/8 inch wide.
- 2) Shooting the old pavement surface with an AR 2000 or 4000 grade asphalt cement at an application rate of 0.10 to 0.15 gallons per square yard.

- 3) Roll out the fabric and smooth with hand pushbrooms to eliminate all wrinkles.
- 4) Apply another shot of asphalt at a rate of about 0.10 gallon per square yard. This shot should be adjusted to completely saturate the fabric.
- 5) Apply the asphalt overlay.

FHWA (24) recommends the following design procedure:

- 1) Uncracked Pavement (no reflective cracking problem):
Overlay thickness is the thickness required by the structural need of the pavement.
- 2) Cracked Pavement (potential reflective cracking):

Overlay thickness is the thickness required by the structural need of the pavement plus the thickness required to prevent reflection cracking; 2-1/2 inches (dense graded hot mix) without fabric, or 1-1/2 inches with fabric.

CHAPTER 3. EXAMPLES OF PREVIOUS EXPERIENCE

3.1 HOT-MIX ASPHALT CONCRETE OVERLAY

The hot-mix asphalt concrete overlay is the most conventional method of rehabilitation of both high-volume and low-volume roads. ADOT is commonly using this kind of rehabilitation technique on LVR. Although this technique is successful other less expensive rehabilitation techniques could be more cost-effective.

3.2 SURFACE RECYCLING

Different types of surface removal and surface recycling are 1)cold planing, 2)heater-planing, 3)cold-milling, and 4)heater scarifying. Various states have used these surface recycling methods to treat surface distress. Many agencies reported successful surface recycling jobs on LVR.

The experience of ADOT with surface recycling on LVR is very limited. Only a few heater-planing and heater-scarifying jobs have been performed. In the heater-scarifying jobs, there were some concerns over developing bleeding. Almost no cold milling on LVR has been used by ADOT.

3.3 COLD-MIX RECYCLING

Cold-mix in-place asphalt pavement recycling has gained wide acceptance in the last two decades. Numerous cold, in-

place recycling (CIR) projects were performed in various states and around the world, with good success in most cases (12-16, 26-29). The recycled mat is usually treated with a sand seal or a chip seal. In some projects the recycled mat is overlayed with hot-mix asphalt concrete.

However, many states, including Arizona, remain skeptical of the use of cold in-place recycling because of the lack of long-term performance data and adequately documented field engineering studies. Furthermore, because of the variability in construction processes with substantially different design concepts and end-results, the term cold in-place recycling is often misunderstood.

One of the states which has good experience in cold in-place recycling is Oregon (29). Five hundred miles were cold-recycled between 1984 and 1989 as one alternative to conventional practices for the rehabilitation of asphalt concrete pavements. All CIR efforts have consisted of partial-depth (AC-surface) recycling on low-volume roads--generally less than 2,000 average daily traffic--with good success on most projects. Projects have also been completed on county roads and U.S. Forest Service roads using this technique. In most cases, the recycled mat is treated with a sand seal or a chip seal. Construction costs for this operation are on the order of \$1.70 to \$2.10 per square yard compared with \$2.75 to \$4.00 per square yard for a conventional 2-in. overlay. The experience of Oregon state indicates that over 75 percent of the CIR projects in Oregon

since 1984 were rated fair or better in 1984 to 1989. It was also shown that CIR can provide significant savings realized through conservation of energy and costly construction materials. On the basis of the results of the state's practice to date, it appears that CIR is a viable rehabilitation alternative for low-volume roads. Hence, using the CIR concept on higher-volume roads (including Interstates) is now proposed (29).

Typical costs for construction and maintenance of cold in-place recycling versus hot-mix projects in Oregon are presented in Table 3.1 (29).

ADOT did not have much experience in cold in-place recycling. Only 4 CIR projects were constructed since 1981 as shown below.

<u>Route</u>	<u>Location</u>	<u>Length (mi)</u>	<u>Date</u>
U.S. 70	Globe	5	1981
U.S. 70	Globe	8.8	1983
S87	Near Picacho	5.25	1983
I-10(frontage road)	Near Picacho	8.25	1987

Out of the four ADOT CIR projects, hot-mix overlay was placed on the recycled mat of one of the projects in Globe. Seal coat was applied on the recycled mat in the other three projects. Some problems related to the low curing time were developed in the two projects near Picacho. More frequent maintenance was conducted on the CIR sites as compared to hot-mix overlaid sites. Although there was a saving in the initial cost of rehabilitation, it was not clear if the CIR

Table 3.1. Typical costs for cold in-place recycling
versus hot mix - Oregon DOT

Item	Construction Cost	Maintenance Cost
CIR (2-in.) with chip seal	\$1.70 - \$2.10/sq.yd.	Best Case: Maintenance of \$1200/mi/yr beginning in 6th year and increasing 25% each year. Worst Case: Maintenance of \$1200/mi/yr beginning in 3rd year and increasing 25% each year
CIR (2-in.) with 1½-in. OGEM	\$2.20 - \$3.00/sq.yd.	\$8,700/mile after 7 years (chip seal)
2-in. Hot Mix Overlay	\$2.75 - \$4.00/sq.yd.	Maintenance of \$1200/mi/yr beginning in 8th year and increasing 25% each year

projects were cost effective in the long term due to the higher maintenance cost.

Cold-mix central plant recycling has not been very common in Arizona. In fact, only a few cold-mix central plant mixes have been prepared by ADOT. On the other hand, cold-mix central plant recycling using emulsion or cutback has been used by other states especially for use in patching during the winter season when the hot-mix plants are closed.

3.4 HOT-MIX RECYCLING

Hot-mix recycling has been used only in central plants where the recycled asphalt pavement (RAP) material is mixed with virgin asphalt and aggregate and heated to prepare recycled asphalt concrete. ADOT is currently using the hot-mix recycled asphalt concrete for high-volume roads. Usually 50% virgin material is added to the RAP material in ADOT mixes and used in the lower lift of the overlay. The top lift of the overlay is usually virgin asphalt concrete.

Hot-mix recycling (milling-and-replacing) on LVR has not been commonly used by ADOT due to the long time it takes for the RAP material to be sent to a central plant for recycling and returned to the same site. This process usually creates problems due to closing the road to traffic for a long time considering the fact that LVR are usually 2-lane roads and detouring the traffic is difficult.

3.5 ASPHALT RUBBER

Many asphalt-rubber projects have been constructed in various states and around the world. In 1989 the Asphalt Rubber Producers Group (ARPG) conducted a survey to evaluate various asphalt rubber projects (30). Thirty-five projects placed in 12 states since 1975 were evaluated. The survey concluded that, in spite of the unscientific methods used to design mixes and maintain quality control, asphalt-rubber is very forgiving. Thirty-three of the 35 projects are still performing equally or better than standard asphalt concrete.

The Arizona Department of Transportation has been a prime sponsor for the development and use of asphalt-rubber. ADOT began constructing SAM test sections in 1967. SAM's were placed on severely distressed pavements that would otherwise require a thick structural overlay or reconstruction. Based on the performance of these sections, ADOT funded several laboratory research projects to examine the engineering properties of asphalt-rubber. The research sponsored by ADOT demonstrated a significant improvement in the elasticity of asphalt through the addition of rubber. Based on the laboratory and field research, ADOT adopted the use of SAM and SAMI sections as a pavement rehabilitation option. Several SAM and SAMI sections were constructed throughout the state and on all classes of highways as shown below. Except for the test section constructed in 1967, all of these sections were constructed between 1972 and 1983.

	<u>Interstate</u>		<u>State</u>		<u>U.S.Routes</u>	
	Projects	Mileage	Projects	Mileage	Projects	Mileage
SAM	9	51	11	83	17	142
SAMI	7	56	14	64	36	164

The performance of the asphalt-rubber sections with respect to cracking and roughness was evaluated (18). In general, the performance of the sections with respect of cracking was excellent. Few of the asphalt-rubber sections displayed significant amounts of cracking. On the other hand, the performance of the asphalt-rubber sections with respect to roughness was about the same as the performance of the conventional sections. Recently, SAM has been rarely used by ADOT, while SAMI is used sometimes. In addition, asphalt rubber concrete is sometimes used in overlaying high-volume roads and in asphalt concrete friction courses (ACFC).

The City of Phoenix has many years of experience with asphalt-rubber mixes (31, 32). Good pavement performance was reported for test sections paved with asphalt rubber concrete.

Research projects are being conducted on the properties and performance of asphalt rubber. The U.S. Corps of Engineers is working in a research project to evaluate and develop mix designs for asphalt-rubber concrete (30).

It should be noted that the asphalt rubber concrete is more expensive than conventional asphalt concrete. However, asphalt rubber concrete could last longer than conventional asphalt concrete, or thinner sections could be used.

3.6 FOAMED ASPHALT

Almost all the foamed asphalt has been used to stabilize base courses and local aggregates for use in low-volume roads. Many field tests have been built using foamed asphalt and many laboratory tests have been conducted to investigate the properties of foamed asphalt (33,34). A laboratory research study was conducted in Arizona in which additives were added to the foamed asphalt mix in order to improve its properties (23).

It seems that foamed asphalt has been used only for stabilizing base courses and local aggregates and not for rehabilitation of existing asphalt pavements per se. ADOT has very limited experience with foamed asphalt.

3.7 FABRICS

For the purpose of pavement rehabilitation, fabrics have been generally used in conjunction with an asphalt overlay. A 4-ounce per square yard, or heavier, needle-punched non-woven fabric is recommended (24). The wovens and the hot-rolled heat-bonded fabrics are not recommended for waterproofing or crack reflection prevention because their smaller thickness allows them to hold less asphalt and makes them more sensitive to variations in the asphalt application rate.

Some unreported work by researchers indicates that shot of 0.20 to 0.25 gallon per square yard of asphalt without fabric may be as effective as with fabric in reducing

reflection cracking. They theorize that cracks which develop heal themselves if a supply of asphalt is available. This laboratory work has not been verified in the field. Large areas treated in this manner would probably fail by slippage similar to an application of a tack coat that is too heavy. This should not be a problem on very small areas or widely spaced cracks, i.e., thermal cracks.

Fabrics have also been used with seal coats and surface treatments. Their principal benefit is probably derived from waterproofing.

An application which may have promise is in conjunction with open graded pavements placed over water sensitive bases and/or subgrades. When placed below or between lifts of the open graded material, it should provide the needed water barrier or seal.

Several other references are available which show the fabrics experience (35-37). ADOT has very limited experience with fabrics for pavement rehabilitation.

CHAPTER 4. RECOMMENDATIONS

FOR ADOT USE

Highway engineers responsible for maintaining and rehabilitating low-volume roads are usually faced with a staggering set of needs, limited resources, and a sea of technical information. The main purpose of this report is even to reduce the money spent on LVR by recommending the use of inexpensive rehabilitation strategies. Therefore, there is a large need to optimize the use of the available resources and to use the most cost effective method of rehabilitation.

Various methods of maintenance and rehabilitations are discussed in Chapter 3. These maintenance and rehabilitation techniques are:

Maintenance Techniques

- Crack sealing
- Patching
- Maintenance at utility cuts
- Surface seal coats (chip seal, sand seal, fog seals, asphalt rubber seals, and slurry seals)

Rehabilitation Techniques

- Overlay
- Surface recycling (cold planing, heater-planing, cold milling and heater-scarifying)
- Cold-mix recycling (in-place and central plant)
- Hot-mix recycling (central plant)
- Asphalt rubber
- Fabrics

A DOT engineers have extensive experience in most of these maintenance and rehabilitation techniques. Some

techniques, however, have not been extensively used for one reason or another. Based on the literature search and personal contacts with ADOT engineers, the following rehabilitation alternatives and recommendations are derived for use by ADOT.

1. Use of Surface Recycling

Various types of surface recycling (cold planing, heater planing, cold milling and heater scarifying) could be viable rehabilitation alternatives for ADOT LVR. Of course, this type of treatment is only suitable for correcting surface distress such as nonload-associated cracking, minor rutting or minor corrugations. The use of one or more of these surface recycling techniques could reduce the cost of rehabilitation and/or extend the life of LVR.

2. Use of Cold-Mix In-Place Recycling

As indicated earlier cold-mix in-place recycling has been used by ADOT on only 4 sites. This kind of recycling has been extensively used by many other states as a viable rehabilitation alternative for LVR. The recycled mat can be further treated with a sand-seal or a chip seal. This rehabilitation alternative can treat all types and degrees of pavement distress and can improve the ride quality. It has been proven by other highway agencies that this rehabilitation technique is less expensive than conventional hot-mix asphalt concrete overlay. The amount of saving in

initial cost varies depending on the method and equipment used, and is expected to be in the order of 25-40%.

The equipment required for cold in-place recycling is available to most local paving companies. Either the conventional cold-mix in-place recycling or the pulverization-and-mixing train concept, similar to that used in Globe, Arizona in 1981 and 1983, can be used by ADOT in a more frequent manner.

3. Use of Hot-Mix Central Plant recycling

One of the problems that is limiting the use of hot-mix recycling on LVR by ADOT is the long time it takes to mill the site, send the millings to a central plant for recycling and returning the recycled mix to the same site. If a large amount of LVR recycling is used, millings could be stored in the central plant and used on any recycling site and not necessarily sent back to the same site where the millings were obtained. This process could increase the use of hot-mix recycling on LVR which could provide saving in the cost of materials.

4. Use of Fabrics

Fabrics could be used as a waterproofing and/or stress-releasing layer between the old AC layer and the overlay. This could result in reducing the reflection cracking and increasing the life of the overlay. Also, a thinner overlay

could be used with fabrics which could result in reducing the rehabilitation cost.

5. Use of Surface Seal Coats instead of Overlays

Depending on the type of distress, surface seal coat techniques such as chip seals, sand seals, fog seals and slurry seals could be used instead of overlays. Surface seal coat might not last for the same period of an overlay, but could be more cost-effective in some cases.

6. Use of Thin Overlays

In a previous study conducted at Arizona State University for ADOT(38) statistical analysis showed that if the main purpose of overlay is excessive roughness, a relatively thin overlay (about 2 inches) is just as effective as thick overlay in reducing the roughness for Arizona Interstate, U.S., and State routes. If this is also applicable to LVR, thin overlays could be used for LVR instead of thick overlays. Thin overlays (1 in.) have not been considered in the study (38).

7. Use of ACFC More Frequently

Again, the ASU Study (38) showed that the use of ACFC layer has significantly reduced the rate of development of roughness on U.S. and State routes in Arizona. If this is true for LVR, the use of ACFC on LVR could increase the life of LVR which in turn could reduce the life cycle cost.

8. Use of Economic Analysis

The comparison between different rehabilitation alternatives should not be based only on initial cost. Of course, initial cost is important but it should not be the only factor. Life cycle cost analysis should be used to select the most cost-effective alternative. Costs that should be considered are: initial construction cost, future maintenance cost, future rehabilitation or reconstruction cost, peripheral cost, user cost, and salvage cost.

9. Use of Pavement Management System

Pavement management system should be used to evaluate various rehabilitation strategies of LVR continuously over the years and monitor their performance. A feedback system should also be used to upgrade the Department's policies and decisions.

CHAPTER 5. CONCLUSIONS

A literature search was conducted in this study in order to evaluate various maintenance and rehabilitation strategies applicable to low-volume roads. Some ADOT engineers were contacted to acquire the current practice followed by the state. It was found that the common method of LVR rehabilitation used by ADOT is the hot-mix asphalt concrete overlay. Although other rehabilitation techniques have been used throughout the years, many of these techniques have not been used frequently. One of the reasons for not using many of these rehabilitation alternatives could be the reluctance to take the risk and try a new alternative that could not be successful. Some of these alternatives could be cost-effective as proven by other highway agencies, and the only way to prove their efficiency in the state is to try them.

It is recommended that ADOT would use other rehabilitation techniques on LVR more frequently such as surface recycling, cold-mix in-place recycling, hot-mix recycling, fabrics, and thin overlays. The decision to use these rehabilitation techniques and others should not be based only on the initial construction cost but should be based on a sound life cycle cost analysis. A good pavement management system should also be used in order to evaluate the cost-effectiveness of each technique so that more efficient decisions can be taken in the future.

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